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PREDICTION OF IRREGULAR WAVE RUNUP.(U)  
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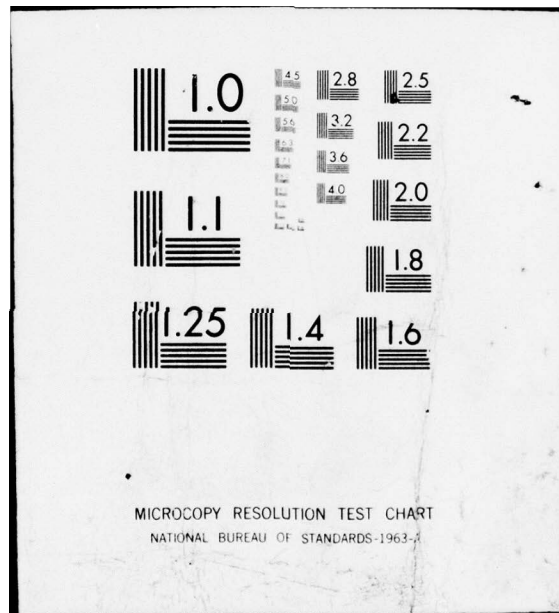
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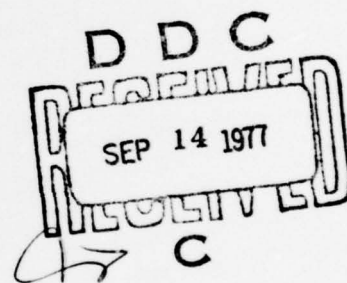
# Prediction of Irregular Wave Runup

by

John Ahrens

COASTAL ENGINEERING  
TECHNICAL AID NO. 77-2

July 1977



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purposes. A method of correcting runup for slope roughness and porosity, which is easier to apply than the method presented in SPM, is also presented. Example problems are given using these techniques for both plain and composite slopes.

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## PREFACE

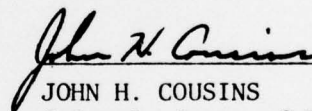
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This report was prepared by John Ahrens, Oceanographer, Coastal Structures Branch, under the general supervision of Dr. R.M. Sorensen, Chief, Coastal Structures Branch.

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Comments on this publication are invited.

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JOHN H. COUSINS  
Colonel, Corps of Engineers  
Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)  
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.39	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	$1.0197 \times 10^{-3}$	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins <sup>1</sup>

<sup>1</sup>To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula:  $C = (5/9) (F - 32)$ .

To obtain Kelvin (K) readings, use formula:  $K = (5/9) (F - 32) + 273.15$ .

## SYMBOLS AND DEFINITIONS

$d$	water depth
$d_s$	water depth at toe of structure
$H$	wave height
$H'_0$	equivalent deepwater wave height
$H_p$	wave height associated with a particular probability of exceedance
$H_s$	significant wave height
$p$	probability of exceedance
$R_p$	wave runup associated with a particular probability of exceedance
$R_s$	design significant wave runup; i.e., runup caused by a wave with significant height and period
$r$	runup correction factor for roughness and porosity
$T$	wave period

# PREDICTION OF IRREGULAR WAVE RUNUP

by

*John Ahrens*

## I. INTRODUCTION

This report provides a technique for predicting the runup of irregular wind-generated waves of the type observed in most coastal waters. No guidance for prediction of irregular wave runup is currently available in the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975) or other Corps publications. Therefore, this interim guidance is provided until results of the Coastal Engineering Research Center (CERC) laboratory and field studies of the runup of irregular waves are available.

The approach is consistent with and parallels the SPM development of runup prediction for regular waves of constant period and amplitude. Although quite simple, this approach gives a reliable estimate of the extreme values of irregular wave runup. Because of the method of formulation, the runup estimates are conservative in that they yield somewhat higher extreme values than would be predicted by more complex prediction techniques; e.g., Saville, McClendon, and Cochran (1962). A conservative approach is desirable because there are little field or laboratory data to substantiate any prediction technique for irregular wave runup.

## II. PREDICTION OF THE DESIGN SIGNIFICANT WAVE RUNUP

The technique for regular wave runup prediction in the SPM (Sec. 7.21) is used to predict the runup for the design significant wave. That value is dependent on slope roughness and porosity and an easier method to determine this influence is given in this report (Sec. III). This adjusted significant wave runup is then used to predict the irregular wave runup distribution (see Sec. III).

The first step in calculating the design significant wave runup is to select the design wave or waves. Selection is based on many factors (discussed in the SPM, especially Sec. 7.12), but ultimately the problem can be reduced to selection of a design significant wave height and period. The runup predicted by SPM for a wave with the design significant height and period will be referred to as the design significant runup,  $R_s$ .

Using the equivalent deepwater significant height and period for the design wave, the runup for this wave on a smooth slope can be calculated as shown in SPM (Sec. 7.21). When the runup is corrected for scale effects (see Fig. 7-13 of the SPM), it is the  $R_s$  for a smooth, impermeable structure.

If the structure being designed is not smooth, roughness and porosity may be accounted for by using the SPM method (Sec. 7.21) or by applying a

correction factor. The roughness and porosity correction factor,  $r$ , is the ratio of the runup on a rough permeable or rough impermeable slope divided by the runup on a smooth impermeable slope; i.e.,

$$r = \frac{R_s \text{ (rough slope)}}{R_s \text{ (smooth slope)}} \quad (1)$$

A compilation of  $r$  values used for selecting  $r$  is shown in a Table from Battjes (1974). The table includes an entry by McCartney and Ahrens (1975). The values of  $r$  as determined by these sources are relatively consistent.

### III. ESTIMATING THE RUNUP DISTRIBUTION

The approach assumes that the individual wave runup elevations have a Rayleigh distribution of the type commonly associated with the distribution of wave heights at sea. Saville (1962), Saville, McClendon, and Cochran (1962), van Oorschot and d'Angremond (1968), and Battjes (1971, 1974), suggest that a Rayleigh distribution for runup is plausible and probably conservative for runup caused by naturally occurring wave conditions. The runup distribution is then given by:

$$\frac{R_p}{R_s} = \left( \frac{\ln (1/p)}{2} \right)^{1/2}, \quad (2)$$

where  $R_p$  is the runup associated with a particular probability of exceedance,  $p$ . For example, assume a desire to know the 1-percent runup, i.e., the elevation exceeded by 1 percent of the runups, then  $p = 0.01$  and equation (2) yields:

$$\frac{R_{.01}}{R_s} = \left( \frac{\ln \left( \frac{1}{.01} \right)}{2} \right)^{1/2} = 1.517.$$

This indicates that the 1-percent runup would be about 52 percent greater than  $R_s$ . A graph of equation (2) showing  $R_p/R_s$  versus  $p$  is given in a Figure. Note that the percent runup (or wave height) means the percent exceedance and not the average value for the given percent as used in many sources. The figure or equation (2) can also be used to determine the percent exceedance for wave heights (i.e.,  $H_p/H_s$ ) having a Rayleigh distribution.

### IV. EXAMPLE DESIGN PROBLEMS

\* \* \* \* \* EXAMPLE 1 \* \* \* \* \*

To illustrate the application of this approach to irregular wave runup prediction, consider the example given in SPM (p. 7-24).



Table. Values of  $r$  for various slope characteristics  
(from Battjes, 1974).

Original source	Slope characteristics	$r$
-----	Smooth, impermeable	1.0
Shankin	Concrete blocks	0.90
H.L. Delft	Basalt-covered stone blocks	0.85 to 0.90
CERC <sup>1</sup>	Gobi blocks	0.85 to 0.90
Franzius	Grass	0.85 to 0.90
CERC	One layer of rubble (impermeable foundation)	0.80
Shankin	Set stone	0.75 to 0.80
Shankin	Round stones	0.60 to 0.65
H.L. Delft	Rubble	0.50 to 0.60
H.R.S. Wallingford	Rubble	0.50 to 0.55
Shankin	Broken rubble	0.50 to 0.55
CERC	Two or more layers of rubble	0.50
Starosolszky	Tetrapods	0.50

<sup>1</sup>Added to Battjes (1974) original table (from McCartney and Ahrens, 1975).



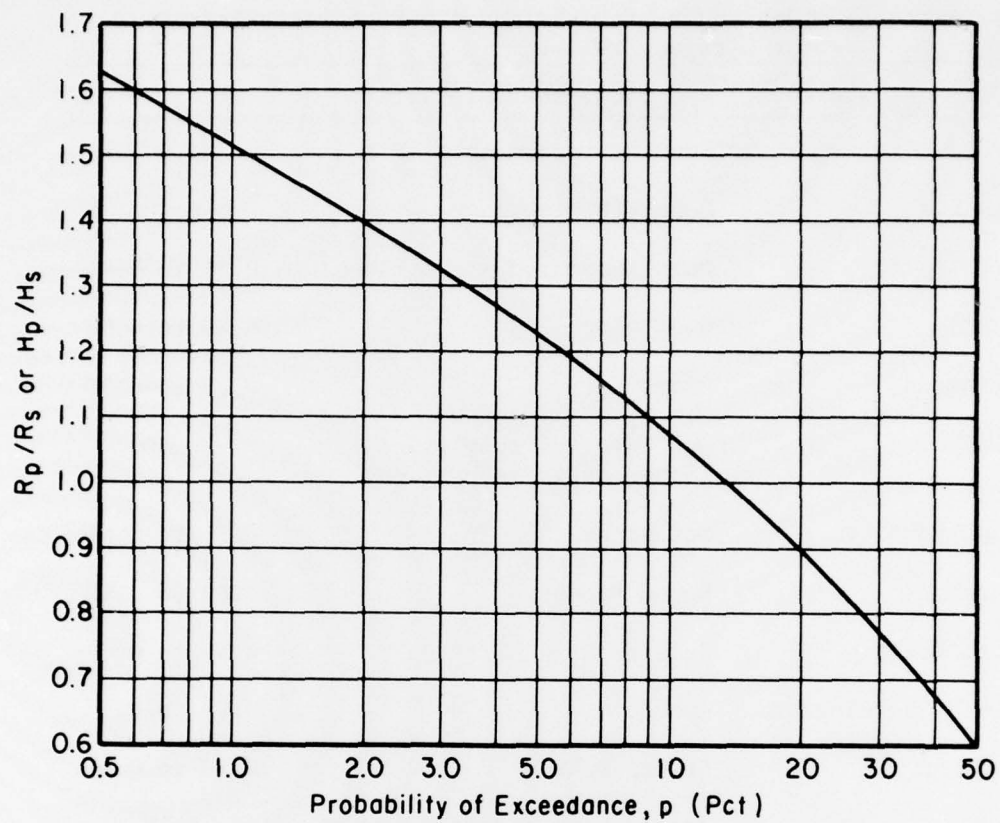


Figure. Relative runup,  $R_p/R_s$ , or relative wave height,  $H_p/H_s$ , as a function of the probability of exceedance,  $p$ .

GIVEN: An impermeable structure with a smooth slope of 1 on 2.5 and subjected to a design wave,  $H = 7$  feet, measured at a gage located where the water depth,  $d = 15$  feet. The design period,  $T = 8$  seconds. Design depth at the structure toe at high water,  $d_g = 10$  feet. (Assume no change in the refraction coefficient between the structure and the wave gage.)

FIND:

- (a) The height above the stillwater level (SWL) to which the structure must be built to prevent overtopping by the design wave.
- (b) The reduction in required structure height if uniform-sized riprap is placed on the slope.

SOLUTION: Although the given wave is not specifically defined, it is convenient to consider the wave as the significant wave of the design storm. In addition, instead of no overtopping by the design wave, assume that it is required to compute the elevation overtopped by only 1 wave in 20 during the design storm; i.e.,  $p = 0.05$ . In the SPM,  $R_g$  was 21.3 feet; therefore, from equation (2):

$$\frac{R_{.05}}{R_g} = \frac{R_{.05}}{21.3} = 0.707 (\ln 20)^{1/2} = 1.22$$

and  $R_{.05} = 1.22 (21.3) = 26.1$  feet.

To find (b) above, the roughness and porosity factor from the Table is estimated as:

$$r = 0.50$$

This yields:

$$R_g = R_g(\text{smooth}) \times r = 21.3 (0.50) = 10.65 \text{ feet.}$$

The 5-percent runup corresponding to  $R_g = 10.65$  feet is

$$R_{.05} = 10.65 \times 1.22 = 13.0 \text{ feet .}$$

\* \* \* \* \* EXAMPLE 2 \* \* \* \* \*

Saville (1958) presented a method for determining  $R_g$  on composite slopes using the results obtained for constant slopes (see SPM example, pp. 7-33 to 7-37). The technique discussed in this report can be applied to composite slopes and should give conservative results for  $R_p/R_g > 1.0$ , if  $R_g$  is found to exceed the berm or slope break elevation. This can be shown by using the conditions given in the SPM example.

GIVEN: A smooth-faced levee (cross section in SPM, Fig. 7-21) is subjected to a design wave having a period,  $T = 8$  seconds and an equivalent deepwater height,  $H'_0 = 5$  feet. The depth at the structure toe,  $d_g = 4$  feet.

Again, it is assumed that the given design height and period are the significant values. It is also necessary to modify the question slightly to account for the irregularity of actual surf conditions.

FIND: The elevation which will be exceeded by only 1 wave runup in 20,  $R_{.05}$ .

SOLUTION: From example 1:

$$\frac{R_{.05}}{R_g} = 1.22 ,$$

and from the SPM example,  $R_g \approx 6.04$  feet; therefore,

$$R_{.05} = 6.04 \times 1.22 = 7.4 \text{ feet}$$

To determine if the above solution provides a conservative runup estimate, estimate the runup of the 5-percent wave,  $H_{.05}$ ; i.e., the wave with a height exceeded by only 1 wave in 20. This approach is adopted since it is initially suspected that the largest waves cause the highest runups. Assuming the Rayleigh distribution holds, the deepwater height of this wave is:

$$H_{.05} = 5 \times 1.22 = 6.1 \text{ feet}$$

and the wave period is most likely the same as for the significant wave; i.e.,  $T = 8$  seconds, since waves higher than the significant wave usually have a period close to the significant period. Following the procedure given in the SPM example, the runup on the compound slope for  $H_{.05}$  is 5.7 feet, which is lower than  $R_g$  as determined in this example.

Although surprising, this result is logical. Because the fronting slope is so flat (1 on 20), the larger wave breaks much farther offshore than the significant wave and therefore loses considerably more energy before encountering the structure. This analysis suggests that  $R_{.05} = 7.4$  feet may actually be too conservative. However, another component in the incident wave spectrum is probably responsible for the highest runups; e.g., the wave having the maximum breaker height in a water depth of 4 feet, the depth at the toe of the 1 on 3 slope. The maximum breaker height for  $d_g = 4$  feet and  $T = 8$  seconds is 5.24 feet, and following the procedures in SPM this wave would run up about 7.4 feet, or approximately the value estimated for  $R_{.05}$ .

## V. SUMMARY

This report presents a technique for estimating the wind-wave runup distribution on structures by extending the traditional method of runup prediction for regular waves developed in the SPM (Sec. 7.21). The technique assumes that the runup has a Rayleigh distribution of the type commonly observed for wave heights. Application of the technique to both plain and compound slopes is shown by example design problems and appears to give conservative but reasonable estimates of the runup distribution. In situations where the offshore slope and depth cause the larger waves to break offshore, the elevations predicted by the technique appear to become increasingly more conservative as the percent exceedance becomes smaller. As a practical guide for this type of situation, the runup will probably not exceed elevations of about 1.4 to 1.5  $R_g$ .

A method of correcting the influence of slope roughness and porosity on wave runup, which is easier to apply than the SPM method, is also presented.



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